

June 9, 2025

Aziz Mahar, PE
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Washington State Department of Ecology
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Olympia, Washington 98504-7775

Re: Project Macoma (Permit No, WA0991051) Dye Study Work Plan Transmittal and Clarifications

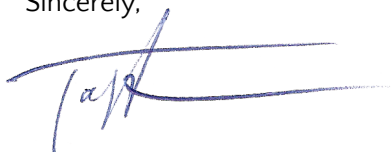
Dear Mr. Mahar,

Thank you for our recent meeting to discuss the development of the attached Dye Study Work Plan and updates to the approach to commissioning and startup of the Project Macoma marine carbon dioxide removal (mCDR) pilot study. We are prepared to implement the Dye Study Work Plan on July 2, 2025 in accordance with the attached. If there is a revision required to this date, we will notify you as soon as possible. The Dye Study will be conducted over an approximately 10 hour period likely initiating at approximately 7am.

As you know, the Dye Study is a component of the Ecological Safety Methodology that is a component of the Permit. As Project Macoma has advanced construction and commissioning, it has determined that the study will be conducted with raw seawater and a small amount of Rhodamine WT dye, a US EPA approved non-toxic dye that will be diluted to the point that is unlikely to be visible to the human eye. To prepare for the Dye Study, Project Macoma will need to extract and discharge raw seawater. In addition, discharges of raw seawater may be required after the dye test for commissioning, to prepare for releases of maintenance and routine discharges under ebb tide conditions. It is our interpretation that for startup and commissioning, discharges consisting of seawater only are allowed under any tidal conditions so long as alkaline enhanced seawater discharges are not included.

We appreciate any comments you have related to the dye test study design and verification that the Project Macoma startup and commissioning assumptions are correct.

Sincerely,



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Manager, Project Macoma LLC



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Technical Memorandum

Prepared for: Ebb Carbon

Project Title: Dye Tracer Study

Project No.: 203681

Technical Memorandum

Subject: Dye Tracer Study Plan

Date: June 6, 2025

To: Todd Pelman, Ebb Carbon

From: Matt DeBoer, Brown and Caldwell

Prepared by: Matthew J. DeBoer
Matt DeBoer, P.E., Washington License 40948, Expires 4/11/2027

Reviewed by: David McBride
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Limitations:

This document was prepared solely for Ebb Carbon, Inc., in accordance with professional standards at the time the services were performed and in accordance with the contract between Ebb Carbon, Inc., and Brown and Caldwell dated May 7, 2025. This document is governed by the specific scope of work authorized by Ebb Carbon, Inc.; it is not intended to be relied upon by any other party except for regulatory authorities contemplated by the scope of work. We have relied on information or instructions provided by Ebb Carbon, Inc., and other parties and, unless otherwise expressly indicated, have made no independent investigation as to the validity, completeness, or accuracy of such information.

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Section 1: Introduction

Ebb Carbon has developed a marine carbon dioxide removal (mCDR) system to safely and permanently remove carbon dioxide from the atmosphere while reducing seawater acidity locally. The mCDR system uses an electrochemical process to remove acid from ambient seawater. The produced alkaline seawater is returned to the receiving water where it can absorb atmospheric carbon dioxide and store it as bicarbonate, a safe and naturally abundant form of carbon storage in the ocean that doesn't acidify seawater.

Project Macoma, LLC, a wholly owned subsidiary of Ebb Carbon, is a pilot-scale facility constructed at Terminal 7 of the Port of Port Angeles in Port Angeles, Washington. The Project Macoma facility includes a barge-mounted seawater intake and discharge outfall connected to process equipment and storage at the shoreline, as shown in Figure 1.



Figure 1. Project Macoma, LLC facility

This Study Plan (Plan) outlines the methodology for completing a dye tracer study for the Project Macoma, LLC discharge to Port Angeles Harbor. The field data collection and subsequent model analyses described in this Plan will be used to directly measure the degree of discharged effluent and receiving water mixing. Data collected will be used to assess and validate model input values developed for the permit/planning level model analyses previously performed (Brown and Caldwell [BC], 2024) to assess potential water quality impacts of the discharge.

Section 2: Discharge Description

The outfall discharge is a barge-mounted multi-port diffuser located as shown in Figure 1. Water depth at the barge location, immediately adjacent to the pier, is approximately 25 feet mean lower low water. Diffuser design parameters were selected to combine different momentum and negative buoyancy regimes to maintain the effluent plume near the water surface (promoting carbon dioxide absorption) while maximizing dilution. Basic diffuser configuration dimensions are as follows:

- Number of ports = 25
- Port diameter = 0.5 inches
- Port spacing = 2 feet
- Port depth = 6.5 feet
- Port discharge angle = 45 degrees (upward vertically)

During the dye tracer study, Project Macoma, LLC effluent will be simulated by pumping approximately 30,000 liters per hour of ambient seawater through the outfall diffuser. Although density and temperature characteristics of ambient seawater will not be an exact match for the pilot facility effluent characteristics, the simulation will allow for confirmation of diffuser performance prior to initiating the mCDR process. Model adjustments and validation may be performed based on field data collection, if necessary.

Field study measurements will be concentrated within the outfall discharge mixing zone, established in accordance with Washington Administrative Code 173-201A-400. The boundary of the chronic mixing zone (where chronic water quality criteria apply) is located 207 feet in any horizontal direction of any diffuser port and includes the entire vertical water column. Acute water quality criteria apply within a smaller portion of the designated mixing zone, limited to 10 percent of the chronic mixing zone from any diffuser port (20.7 feet), including the entire vertical water column. Figure 2 provides a plan view of the mixing zone with applicable dimensions scaled to the outfall diffuser and in relationship to the Project Macoma, LLC facility.

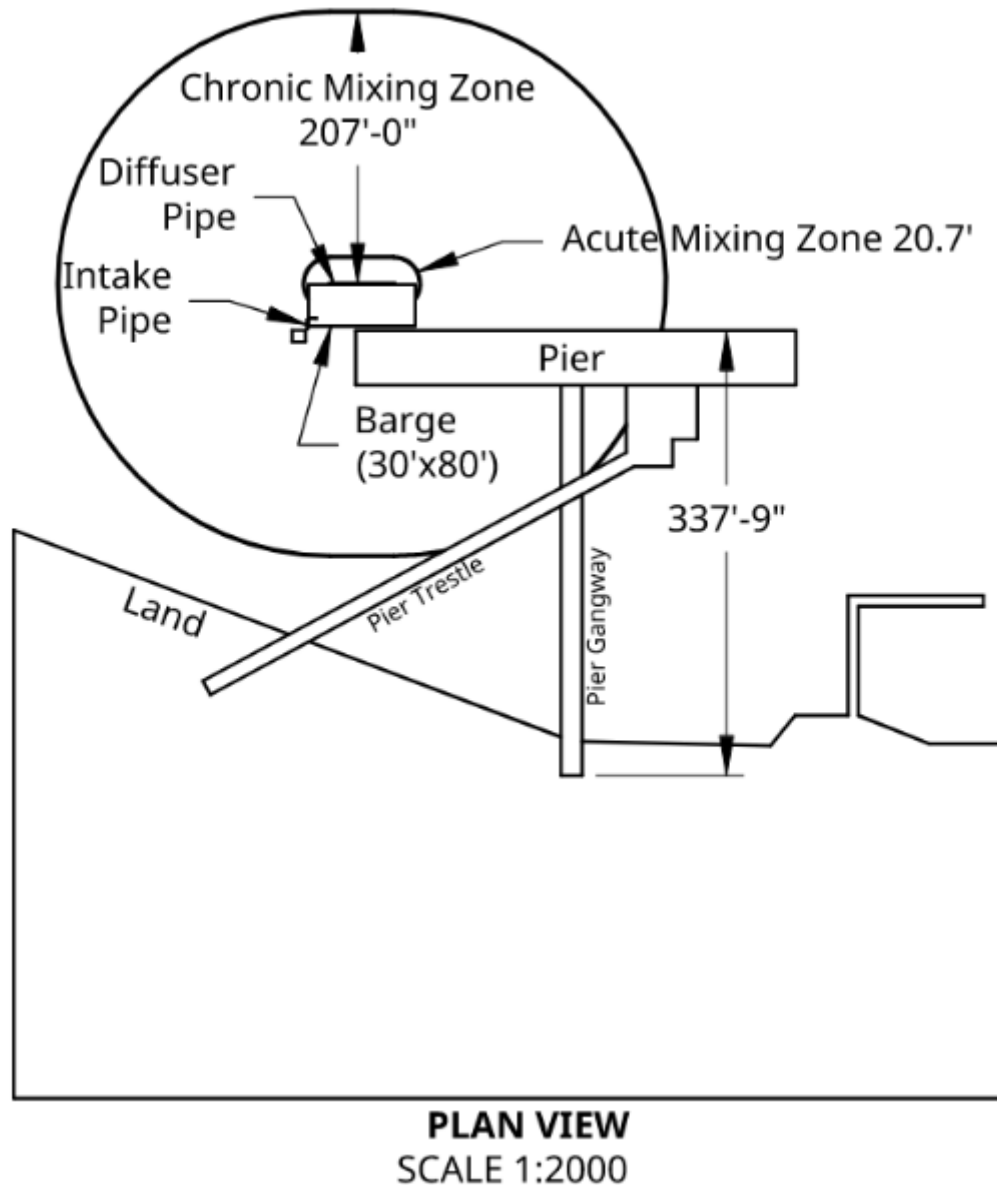


Figure 2. Mixing zone plan view

Section 3: Dye Tracer Study

The following sections describe major elements of the dye tracer study and provide details regarding study methods, instrumentation, monitoring locations, and quality assurance procedures.

3.1 Study Methodology

The study will consist of quantitative dye tracer tests in the field and post-test analyses and interpretation. The following list provides the primary objectives of the study:

- Verify model input parameters for previously completed model analyses.

- Quantify dilution in the immediate area of the discharge.
- Map plume peak dye concentrations (with depth) for calculating estimated dilutions with horizontal distance from the discharge.
- Calculate dilution values observed within the regulatory mixing zone (see Figure 2).
- Validate receiving water current speed assumptions relative to modeled conditions.

The dye tracer field study will consist of a continuous 8-hour release of a non-toxic fluorescent dye into the pumped flow simulating the Project Macoma discharge. Dye concentrations will be measured from discharge pipe samples collected before entering the receiving waters through the diffuser. Receiving water dye concentrations and physical water quality measurements will be collected with boat-mounted instrumentation for the purpose of mapping and quantifying the discharge plume dilution at different times centered around low-water slack tide, which represents minimum dilution conditions accounting for water depth and current speeds.

Current speed measurements will be obtained concurrently using a bottom-mounted Acoustic Doppler Current Profiler, provided and deployed by Ebb Carbon.

3.2 Dye Injection

The dye tracer will be Rhodamine WT, which is a United States Environmental Protection Agency-approved non-toxic dye that can be detected to sub-parts per billion (ppb) levels in typical receiving waters. Because the dye can be reliably measured at such low concentrations using in-situ instrumentation, relatively small amounts are required for performing dilution studies. Rhodamine WT is provided from the manufacturer as a nominal 20 percent solution. At higher concentrations, the dye is brilliant red, but when diluted to the point that it is not visible to the eye, it can still be measured reliably.

The dye tracer will be injected continuously for 8 hours into the pumped flow simulating the Project Macoma facility discharge. The injection rate will be set to target a nominal constant dye concentration of 400 ppb in the effluent. A consistent and stable effluent dye concentration is important for calculating accurate dilutions in the receiving waters.

- **Tracer injection system.** The dye injection will be accomplished using a custom flow-paced precision injection system. The dye injection system is built around a constant displacement pump manufactured by Fluid Metering, Inc., which is monitored and controlled by means of a Campbell Scientific CR1000 measurement and control module. The injection rate will be set based on the pumped flow rate to achieve 400 ppb. It is anticipated that a carrier water system will be used to send metered dye into the pumped seawater for uniform mixing within the discharge. The operation of the injection system will be monitored by onshore staff.
- **Feed dye preparation.** Prior to the start of the dye release, raw dye will be diluted 40:1 with clean water and placed in a sufficiently large carboy to supply the entire injection period without the need to switch containers. Samples of the mixed raw feed dye will be collected for the preparation of dye standards to calibrate dye sensors.

3.3 Sampling Locations

Discharge Measurements

Periodic grab samples will be collected to document the actual discharge dye concentration entering the receiving waters. These samples will be collected approximately every 15 minutes throughout the tracer injection period. The concentration of the grab samples will be measured on a bench-top fluorometer after diluting 40:1 with deionized water to drop the concentration to within the linear measurement range of the



fluorometer. Dye fluorescence is temperature-dependent; therefore, grab samples will be placed in a water bath to equilibrate prior to measurement. The bench-top fluorometer is a Trilogy model by Turner Designs.

Receiving Water Measurements

Dye concentration and physical receiving water quality measurements will be collected in the receiving waters offshore to delineate the horizontal and vertical distribution of the plume using boat-mounted instrumentation. Transects and profiles will be closely spaced in the vicinity of the diffuser, then spread out moving away from the diffuser.

Vertical profiles of water properties and dye will be measured with a Seabird SBE19plusV2 measuring conductivity, temperature, and depth (CTD) (multi-parameter oceanographic water property profiling sonde). Two Turner Designs Cyclops 7 in-situ fluorometers are connected to the CTD. The dual fluorometers provide redundancy and full concentration resolution over four orders of magnitude without delays associated with automatic range changing. Additionally, CTD measurements also include temperature and turbidity. Global Positioning System coordinates will be recorded with each record. Parameters are displayed on a computer monitor in real-time during profiling.

The in-situ fluorometers will be calibrated using calibration standards prepared from the feed dye using volumetric glassware.

3.4 Additional Data Collection

Ebb Carbon will deploy a bottom-mounted Acoustic Doppler Current Profiler offshore of the diffuser to record current speeds and directions in the water column during the dye tracer study. Weather and tide conditions will be compiled to document study conditions.

In addition to mixing zone-targeted data collection, dye concentrations will be measured at the mouth of the closest freshwater source (approximately 1 mile from the discharge) near the end of the field study to assess effluent plume travel during a tidal cycle.

All measurements will be included in the Dye Tracer Study Report.

3.5 Data Processing and Analysis

Post field study data processing includes compiling and consolidating data from all sources, deriving and applying calibration and adjustment factors for dye sensor readings to account for differences between sensors and changing background conditions; removing extraneous sensor readings and data records, and conducting general quality assurance and quality control measures. Data analysis, data interpretation, and report generation follow raw data processing.

Receiving water dye measurements will be compiled to produce graphs/maps of concentration and dilution defining the relative distribution and extent of the dye plume dispersion. Dilution will be calculated using the rate of change of the peak concentration versus distance from the outfall diffuser. Typically, peak dye concentrations correspond to the minimum dilution associated with the center-line of the discharge plume as it moves away from the discharge point.

3.6 Tracer Study Schedule

The field tracer study will be conducted Wednesday, July 2, 2025, with equipment set-up and testing performed on the preceding day. Tentatively, dye injection would begin at approximately 7:00 am with field measurements beginning at approximately 8:30 am to allow for the effluent plume to become established within the mixing zone. Dye injection and field measurements will proceed for up to 10 hours bracketing low water slack tide.



Section 4: Hydrodynamic Model Analysis

Field data collected during the study will be used to visually/graphically adjust and validate the dilution model UM3, as included in the Visual Plumes modeling package (Visual Plumes interface, Frick et al., 2002), if necessary. UM3 modeling was performed previously to support the Project Macoma, LLC permit application process (BC, 2024). Specifically, UM3 was used to predict effluent dilution and plume characteristics with distance from the discharge at the anticipated critical, worst-case conditions for a marine discharge, as defined in the Washington State Department of Ecology Permit Writer's Manual (2018). Previous modeling evaluated a range of facility operating scenarios with associated effluent pH, density, and temperature characteristics.

UM3 model adjustment/validation may be performed using field study data, including dye concentrations, effluent density, receiving water currents, and receiving water density profiles. The field-validated model will use internal model input parameters (adjusted from model defaults) to best align the effluent dilution with distance from the discharge to conditions observed during the field study. For many model input parameters, field study conditions will not match critical conditions. Therefore, the field-validated model settings will then be used to predict minimum effluent dilution at critical discharge and receiving water conditions of the operational mCDR facility to verify or adjust the previous model analyses.

Section 5: Dye Tracer Study Report

A Dye Tracer Study Report will be prepared to present field study observations, collected data, data and model analysis, and conclusions. The following collected data and analyses will be included in the report

- Simulated effluent discharge flow rate and dye concentration.
- Current speed data, including a discussion on how the collected data compares to previously assumed critical current speeds.
- Receiving water density profiles.
- Tabular representation of sample time, location, depth, dye concentration, and calculated dilution.
- Graphical representation of effluent dilution with distance from the discharge. Graphics will include maps showing the dye distribution in vertical and horizontal cross sections.
- Model input data and results for model validation and extrapolation to critical conditions.
- Discussion of model results at critical conditions in comparison to previous model analyses.

Dye tracer study results will inform subsequent permit compliance activities, specifically the Baseline Study Report required as part of the Receiving Water Study (Special Condition S9) (Washington State Department of Ecology, 2024). If the dye tracer field study indicates that the initial model analyses were not conservative or accurate, adjustments will be recommended. Relevant agency stakeholders will be notified of any changes based on dye tracer study results.

References

Brown and Caldwell, 2024. *Port Angeles Mixing Analyses*. Prepared for Ebb Carbon. March 2024.

Frick et al., 2002. *Dilution Models for Effluent Discharges, 4th Ed. (Visual Plumes)*. Athens, GA: Environmental Research Division, United States Environmental Protection Agency.

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